IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

TITLE:

Quartz Arc Tube for a Metal Halide Lamp and Method of Making Same

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Same

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TECHNICAL FIELD

This invention is related to arc tubes used in metal halide
discharge lamps. More particularly, this invention is related to
cylindrical quartz arc tubes for metal halide lamps.

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BACKGROUND OF THE INVENTION

Low wattage metal halide lamps (35-150 Watts) are potential
candidates to replace incandescent lamps in general lighting and
commercial display applications because they offer higher
15 efficacy and longer life. However, compared to incandescent
lamps, low wattage metal halide lamps frequently exhibit
inferior color rendering and variable (lamp-to-lamp) color
consistency. Therefore, alternative design approaches are being
sought to address the color deficiencies, without sacrificing
20 the high efficacy and long life.

In commercial metal halide lamps, the arc tube is made from a
section of quartz tubing. Each end of the quartz tube is pinched
between a pair of opposed jaws to form a gas-tight seal about an
25 electrode assembly while the quartz is in a heat-softened
condition. As a result of this pinch-seal process, the ends
become somewhat deformed and rounded between the cylindrical
main body of the arc tube and the flattened press seal area. The
curved shape of these end wells may vary with the diameter and
30 wall thickness of the original quartz tubing, the heat
concentration during processing, and the pressure of the
enclosed inert gas during pressing.

The photometric performance parameters of metal halide lamps are
dependent on the partial pressures of the enclosed metal halide
salts. Their vapor pressures are primarily controlled by the arc

5   tube wall temperature in the region where the metal halide
vapors condense. This zone is usually located in the lowest
portion of the arc tube due to gravity and internal gas
convection flow. The temperature of this so-called "cold zone"
should be high enough to provide sufficient evaporation of the

10   radiating metal halide species. However, the temperature cannot
be too high otherwise the long life of the arc tube will be
compromised due to chemical reactions with the wall or
devitrification of the quartz. Therefore, a nearly uniform wall
temperature distribution (not exceeding about 900°C for quartz)

15   is desirable for a useful life of more than about 6000 hours.
The 900°C wall temperature is high enough for evaporating many
metal halide salts and low enough to realize a useful life of
the arc tube. In the case of lamps that use quartz arc tubes,
lamp life typically is reduced by a factor of two for every 50°C

20   increase over 900°C.

One of the known means for realizing a more uniform wall
temperature distribution is applying a heat-conserving coating,
such as zirconium oxide, to the outside surface of the end wells

25   of the arc tube. Most conventional metal halide lamps utilize
this heat-conserving coating on one or both ends of the arc
tube. Apart from being an additional cost component, the coating
is itself a significant source of variability in the photometric
performance of such lamps because of intrinsic lamp-to-lamp

30   variation in coating height, adhesion properties, and its
tendency to discolor.

A more effective but more costly way of obtaining a nearly
uniform wall temperature distribution is to form discharge
vessels in elliptical or pear-shaped bodies for vertically
operated lamps or arched tubes for horizontal operation.

5   However, this method does not generally provide for universal
operation of the lamp (i.e., a lamp oriented arbitrarily with
respect to gravity), and requires time consuming glass-working
steps that are not needed for straight tubular body arc tubes.

10   High arc loading (W/cm) and wall loading (W/cm^2) are critical for
improved performance in low wattage metal halide lamps.
Typically, for 35W to 150W quartz-body arc tubes of conventional
design, average electrical wall loading does not exceed 20 W/cm^2
(or 100 W/cm arc loading) in order to obtain an operating life

15   of greater than about 6000 hours. These empirically determined
limits result from the fact that at elevated loading the
temperatures on the arc tube wall become too high for quartz to
survive through the desired life. To remain within these loading
limits, lamp designers have adjusted the arc chamber size and

20   shape, specifically, the electrode insertion length, lamp cavity
length, and lamp diameter in elliptical or ellipsoidal design
arc tubes. Additional control of temperature distributions and
levels in metal halide lamps has been exercised by changes in
the arc tube fill chemistry.

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Cylindrical quartz arc tubes with conservatively low wall
loadings (10-13 W/cm^2) were rejected in the early days (1960's)
of metal halide lamp development because they did not provide
adequate efficiency in low wattage lamps. Nearly symmetric

30   longitudinal, outer surface temperature profiles have been
achieved with ceramic arc tubes having a right circular
cylindrical shape, e.g., U.S. Patent Nos. 5,424,609 and

5,751,111. However, the operating temperatures of ceramic arc tubes is typically above 975°C which far exceeds the 900°C limit for quartz arc tubes.

5 SUMMARY OF THE INVENTION

It is an object of the invention to obviate the disadvantages of the prior art.

It is another object of the invention to provide a quartz arc
10 tube for a metal halide lamp which can be operated at a high average wall loading without exceeding a maximum surface temperature of the discharge chamber of about 900°C.

It is yet another object of the invention to provide a quartz
15 arc tube for a metal halide lamp which has a nearly symmetric longitudinal surface temperature profile when operating at a steady-state thermal condition.

It is still another object of the invention to provide a method
20 for making quartz arc tubes for a metal halide lamps having these desirable properties.

In accordance with one object of the invention, there is provided a quartz arc tube for a metal halide lamp comprising a
25 quartz body enclosing a discharge chamber having a metal halide fill, the discharge chamber having substantially the shape of a right circular cylinder and containing opposing electrodes, the discharge chamber having a nearly symmetric longitudinal surface temperature profile when operating in a steady-state thermal
30 condition wherein the difference between the maximum and minimum temperatures of the profile is less than about 30°C and the maximum temperature of the profile is less than about 900°C.

In accordance with another object of the invention, there is
provided a quartz arc tube for a metal halide lamp comprising a
quartz body enclosing a discharge chamber having a metal halide

5   fill, the discharge chamber having substantially the shape of a
right circular cylinder and containing opposing electrodes, the
opposing electrodes being disposed at each end of the discharge
chamber and coaxial with the axis of the chamber, the distance
between the opposing electrodes defining an arc length, the

10   inner diameter of the discharge chamber in centimeters being
approximately equal to $[(1+P/50)^{1/2}-1]$, where P is the input
power in watts, and wherein the ratio of the arc length to the
inner diameter is about one.

15   In accordance with yet another object of the invention, there is
provided a method of making a quartz arc tube for a metal halide
lamp, the quartz arc tube having a quartz body enclosing a
discharge chamber having a metal halide fill, the discharge
chamber having substantially the shape of a right circular

20   cylinder and containing opposing electrodes, the opposing
electrodes being disposed at each end of the discharge chamber
and coaxial with the axis of the chamber, the distance between
the opposing electrodes defining an arc length, the discharge
chamber having a pierce point where each corresponding electrode

25   enters the discharge chamber, the distance between the pierce
point and the corresponding electrode end within the discharge
chamber defining an electrode insertion length, the arc tube
when operating in a steady-state thermal condition having a
longitudinal surface temperature profile, the method comprising

30   the steps of:

a) selecting an arc length and an inner diameter for the discharge chamber wherein the inner diameter in centimeters is greater than $[(1+P/50)^{1/2}-1]$, where P is the input power in watts, and wherein the ratio of the arc length to the inner

5   diameter is about one;

b) forming the arc tube;

c) operating the arc tube at a predetermined average wall

10   loading to obtain a steady-state thermal condition;

d) measuring a longitudinal surface temperature profile of the discharge chamber to obtain a maximum temperature and minimum temperature;

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e) repeating steps b) to d) while incrementally decreasing the inner diameter of the discharge chamber with each iteration until the maximum temperature of the longitudinal surface temperature profile is midway between the ends of the discharge

20   chamber; and

f) repeating steps b) to d) while incrementally varying the electrode insertion length with each iteration until the difference between the minimum temperature and the maximum

25   temperature of the profile is minimized without causing the maximum temperature to exceed about 900°C.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graphical representation of cold and hot spot

30   temperatures of an operating quartz arc tube of this invention as a function of wall loading.

Fig. 2 is a diagram of a quartz arc tube of this invention.

Fig. 3 is a surface temperature profile of an operating quartz arc tube of this invention.

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Fig. 4 is a surface temperature profile of an operating prior art quartz arc tube.

DESCRIPTION OF PREFERRED EMBODIMENTS

10   For a better understanding of the present invention, together with other and further objects, advantages and capabilities thereof, reference is made to the following disclosure and appended claims taken in conjunction with the above-described drawings.

15

For quartz arc tubes used in metal halide lamps, and in particular low wattage metal halide lamps, we have discovered that a cylindrical discharge chamber having a specific geometry and diameter yields unexpected thermal performance and

20   photometric benefits which allow metal halide lamps to successfully function at high average wall loadings of from about 25 to about 40 W/cm^2 without exceeding the arc chamber's maximum allowed wall temperature of about 900°C. More particularly, the discharge chamber of the quartz arc tube of

25   this invention has substantially the form of a right circular cylinder. After reaching a steady-state thermal condition when operating, the quartz arc tubes of this invention exhibit a substantially symmetric and nearly isothermal longitudinal surface temperature profile as viewed along the axis of the

30   discharge chamber without exceeding the maximum allowed temperature of about 900°C. As defined herein, the longitudinal surface temperature profile is determined along the axis of the

barrel portion of the cylindrical discharge chamber after the

arc tube has reached a steady-state thermal condition during

operation. Preferably, the difference between the maximum and

minimum temperatures of the profile is less than about 30°C, and

5   more preferably less than about 20°C. In addition, the operating

arc tubes exhibit high efficacy, good color rendering

(preferably a CRI of greater than about 80), and improved color

control for universal operation. An additional advantage of the

cylindrical arc tube according to the present invention is that

10   the end paint that is conventionally used to reduce heat loss

from the end wells of prior-art arc tubes is not needed. This

manufacturing and economic advantage is a direct consequence of

the geometrically induced reduction of the temperature gradient

along the outer surface of the discharge chamber.

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Central to the design of the cylindrical quartz arc tube is the

specification of the diameter of the barrel portion of the

discharge chamber. It must be chosen sufficiently small so that

heat transfer from the plasma arc to the chamber wall by gaseous

20   convection is substantially reduced in comparison with that of

quartz arc tubes of conventional design. Satisfaction of this

condition can be ascertained by measuring the steady-state

temperature distribution on the surface of the outer wall of a

vertically operating cylindrical quartz arc tube. When the

25   diameter is too large, the maximum temperature on the outer wall

of the cylindrical chamber will occur near the upper end of the

cylindrical barrel portion, because of substantial convective

heat transport from the plasma arc to the wall. Consequently,

the longitudinal surface temperature profile of the discharge

30   chamber will not exhibit central (mirror-plane) symmetry. This

asymmetric thermal characteristic indicates that heat transfer

from the arc to the wall within the cylindrical discharge

chamber is dominated by gaseous convection. As the diameter of
the cylindrical discharge chamber is decreased, the location of
the maximum wall chamber temperature migrates toward the middle
region of the barrel portion, indicating a transition from heat

5   transfer dominated by gaseous convection to one dominated by
thermal conduction. This is a consequence of the concomitant
reduction of the velocity of the hot gas convecting within the
arc tube. When this occurs, the longitudinal surface temperature
profile of the discharge chamber will exhibit a high degree of

10 central symmetry.

The arc tubes described herein are designed for universal
operation, i.e., operation which is independent of the
orientation of the arc tube with respect to gravity. The arc

15 tube examples provided herein were operated in a vertical
orientation. In general, the plasma arc in an arc tube operated
in a nonvertical orientation tends to bow upwards because of
buoyancy forces induced by temperature gradients within the
plasma arc. However, it is known that an acoustically modulated

20 input-power waveform can be used to achieve straightened arcs in
arc tubes operated in nonvertical orientations, e.g., as
described in U.S. Patent No. 6,124,683 which is incorporated by
reference. Therefore, it is believed that the advantages of
this invention may be achieved in an arc tube operating in a

25 nonvertical orientation if acoustic modulation techniques are
used to maintain a straight arc.

The hot-spot and cold-spot temperatures as a function of average
electrical wall loading (watts/cm^2) for a group of cylindrical

30 quartz arc tubes designed according to this invention are shown
in Fig. 1. As expected, the cold-spot temperature (Tmin)
increased rapidly with increased wall loading, resulting in

improved efficacy, better color rendering and usually lower
color temperature. Surprisingly, the hot-spot temperature (Tmax)
increased at a markedly decreasing rate, thereby exhibiting a
'soft saturation' characteristic. The peak surface temperature

5   of the barrel portion of the cylindrical discharge chamber
reached only 890°C at the very high wall loading of 40 W/cm^2.
The combination of these two effects, i.e., the behavior of the
hot- and cold-spot temperatures with increased average wall
loading, is directly responsible for the improved thermal and

10 photometric performance. This behavior does not occur with
prior-art quartz arc tubes because their barrel diameters are
too large.

In this example, the temperature difference between the coldest

15 and the hottest spots on the barrel of the cylindrical chamber
approached about 20°C, rendering the arc tube surface nearly
isothermal. In thermal equilibrium, an isothermal surface at
temperature T_0 radiates less power than a non-isothermal surface
(with the same area and radiative material properties) having an

20 average temperature of T_0. Therefore, an arc tube with a nearly
isothermal surface temperature operates more efficiently
(thermal losses are reduced or minimized) than an arc tube
having a surface temperature distribution which is less uniform.

25 Referring to Fig. 2, in a preferred embodiment, the quartz arc
tube 2 has discharge chamber 5 containing metal halide fill 10.
Discharge chamber 5 has substantially the form of a right
circular cylinder within the practical limits for conventional
roller forming of the quartz envelope. The discharge chamber

30 has barrel portion 3 having an inner diameter D. Electrodes 7
are disposed at each end of discharge chamber 5 and are coaxial
with axis 14 of discharge chamber 5. The distance between the

ends of the opposing electrodes 7 defines arc length A. The

electrodes 7 are further located in end wells 15 which are

formed at each end of the discharge chamber. The end wells 15

exhibit rotational symmetry because of the basic cylindrical

5   shape produced in the roller-forming operation. The end wells

15 resemble a radially-compressed bottleneck exhibiting circular

symmetry at the ends of the arc chamber. The distance between

pierce point 6 (the point where the electrode enters the end

well) and the tip of the electrode defines electrode insertion

10   length L. Electrodes 7 are welded to molybdenum foils 9 which

are in turn welded to leads 11. The leads 11 are connected to an

external power supply (not shown) which provides the electrical

power to ignite and sustain an arc discharge between electrodes

7. The molybdenum foils 9 are hermetically sealed in the quartz

15   by means of press seals 17 located at each end of arc tube 2.

If for a given lamp input power P (in watts) an average wall

loading of 30 W/cm^2 is assumed and the aspect ratio of arc length

A to the inner diameter D of the barrel portion of the

20   cylindrical discharge chamber is equal to about one ($A/D \cong 1$),

the inner diameter of the discharge chamber, D (in cm), as a

first approximation, is governed by the formula:

$$D \cong (1+P/50)^{1/2} -1$$

25

To optimize the diameter, it is preferred to start with an arc

tube whose inner diameter is somewhat larger than that specified

by the formula cited above. As the diameter is decreased, the

zone (on the outer surface of the cylindrical body) containing

30   the maximum temperature (hot spot) gradually migrates toward a

position midway between both ends of the discharge chamber.

Decreasing the diameter further does not affect the location of
this hot zone, but does cause its peak temperature to increase.
In general, the optimized diameter occurs at the point where the
most nearly symmetric longitudinal surface temperature profile
5   is reached, while simultaneously satisfying the condition that
its maximum temperature does not exceed about 900°C.

After the arc tube diameter is determined, adjustments are made
to the design to further optimize performance. In particular,
10   the electrode insertion length and the shape of the end well may
be adjusted so that the cold-spot temperature on the surface of
the barrel portion is as high as possible without exceeding the
maximum temperature of the hot zone (located on the surface of
the barrel portion nearly midway between the two end wells).
15   Satisfaction of this requirement can be ascertained by measuring
the steady-state longitudinal temperature distribution on the
surface of the wall of a vertically operating arc tube. When the
insertion length is increased, the cold-spot temperature
(typically observed at each end of the barrel portion of the
20   cylindrical discharge chamber) decreases. The optimized
insertion length is the one that maximizes the cold spot
temperature at either end of the cylindrical barrel (for a given
end well shape) without exceeding the maximum temperature of the
hot zone, while simultaneously preserving the central symmetry
25   of the longitudinal surface temperature profile of the
cylindrical discharge chamber.

A surface temperature profile for a vertically operated
cylindrical quartz arc tube designed according to the present
30   invention is shown in Fig. 3. A dotted-line representation of a
cylindrical arc tube has been superimposed on the temperature
profile to show the approximate spatial relationship between the

profile and the arc tube. The profile includes the region of
the arc tube beyond the barrel portion of the discharge chamber.
The temperature profile was measured with an AGEMA thermovision
900 infrared imaging system at 5.0 micron wavelength with a

5   close-up lens to enhance resolution and clarity.

The difference between the maximum and minimum temperatures for
the surface of the barrel portion of the discharge chamber is
about 20°C. Temperature spikes occur at either end of the arc

10   tube at the pierce points where the electrodes enter the end
wells. These pierce points are outside of the barrel portion of
the cylindrical discharge chamber and do not significantly
affect arc tube performance because they occur over a very small
region where the metal salt doesn't reside. The longitudinal

15   surface temperature profile which is determined along the axis
of the barrel portion of the cylindrical discharge chamber shows
a high degree of central symmetry. This is to be compared with a
similar temperature profile shown in Fig. 4 of a prior-art
quartz arc tube having a conventional press-sealed cylindrical

20   body containing the same fill and operating at 100 watts. The
prior-art arc tube exhibits less rotational symmetry than the
roller-formed arc tube of this invention.

The photometric performance characteristics (at 100 hours) of a

25   group of cylindrical quartz arc tubes are compared with those
for conventional quartz arc tubes (press-sealed, cylindrical
body) in Table 1 below. Although the luminous efficacies are
comparable, the spread in correlated color temperature (CCT) is
markedly less, and the color rendering index (CRI) is noticeably

30   improved for the roller-formed cylindrical design of this
invention. The metal halide salt chemistry for these arc tubes
was of the five-component type described in U.S. Patent No.

Table 1

5

	Lumens/Watt	CCT	CRI
Conventional Press-sealed, Cylindrical	87.1	2960 ± 150	72.8
Roller-formed Cylindrical	86.1	3036 ± 75	86.5

While there has been shown and described what are at the present
considered the preferred embodiments of the invention, it will
be obvious to those skilled in the art that various changes and
10 modifications may be made therein without departing from the
scope of the invention as defined by the appended claims.